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## A Real Time Evaluating Method of Aerosol Extinction Coefficients For Multi Laser Wavelengths

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### Abstract

A new real-time evaluating method is proposed for multi laser wavelengths' extinction coefficients of atmospheric aerosol. The back scattered signal measured by single wavelength lidar is utilized together with complex aerosol model of Fascode. The unique features of this method are discussed in detail. Atmospheric aerosol extinction coefficients inversely calculated by this method are compared with real time measurements' data. The results show that it is feasible to evaluate the signatures of infrared atmospheric propagation with reasonable accuracy. The real time atmospheric correcting model is established by the method for aerosol extinction coefficients at different wavelengths without absorption of water vapor. The profile of atmospheric aerosol extinction coefficients for many special wavelengths selected between the spectrum from visible to infrared is evaluated by using both the inversion method and the data measured by 0.532  $\mu$  lidar. The results can be used for atmospheric correction for the laser applications from ground to high-level or vice versa.

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### 1 Introduction

When optical radiation propagating through the atmosphere they interact on each other. The radiation will be attenuated by atmospheric absorption and scattering so that the intensity, frequency, propagation direction and polarization status of the radiation are varied with variation of the atmospheric conditions. At the same time the radiation carries a variety of information of the atmosphere itself. In order to evaluate correctly the radiance arriving at receiving system or to analyse and explain the data measured through the atmosphere the atmospheric transmittance and radiative effect require to be measured in quantity. In consequence a variety of specific devices were investigated and developed. And a lot of experimental measurements were made. At the same time optical radiation transfer model in the atmosphere were investigated widely and deeply. So far the radiation transfer model in the atmosphere have been developed successfully for different purposes with different spectral bandwidth. The famous models are Lowtran for wide bandwidth (20  $\text{cm}^{-1}$ ), Modtran for narrow bandwidth (2  $\text{cm}^{-1}$ ) and Fascode for line by line calculation. Among them Fascode for laser propagation in the atmosphere is valuable for calculating atmospheric transfer of the reflecting or emitting radiation of target and its background.

A new inversion method for evaluating multi wavelengths' atmospheric aerosol extinction coefficients (AAEC) has been proposed based on the real time data detected by single wavelength lidar in conjunction with the FASCODE model. The multi wavelengths' AAEC can be calculated by use of the 'conjunction method' and checked by comparing with other inversion methods. Obviously, designer and simulator for opto-electro system will benefit from this new model. And, the data measured in the atmosphere can be explained correctly and

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quantitatively by use this new conjunction model.

## **2 An inversion method utilized real time measured data in conjunction with FASCODE for calculating multi wavelengths' atmospheric transmittance**

Besides water-vapour and aerosol in the atmosphere there are some atmospheric components, e.g. CO<sub>2</sub>, CO, CH<sub>4</sub>, O<sub>3</sub>, SO<sub>2</sub> etc.. Their content varies with time and space. However, their variation is relatively much slower than the variation of water-vapour and aerosol. Consequently, the fixed value of these components are assumed in atmospheric radiation transfer model. For example, CO<sub>2</sub> volume percent ratio was assumed for 0.0322 % 30 years and more ago. This value was renewed continuously during these years because of variations of earth surface, biosphere, activities of mankind and opto-chemical process in the atmosphere. At present it may approach over 0.04 % at some areas. However, water-vapour and aerosol vary with variation of the atmospheric condition. And, optical thickness of aerosol is related to variation of thermodynamic and kinetic condition in boundary layer of the atmosphere. So that it varies clearly with different time of a day. In consequence, to explore water vapour and aerosol in the atmosphere are needed for explaining and correcting remote sensing data. In the present years as a valuable instrument lidar has been utilising widely for detecting water vapour and aerosol in the atmosphere. Lidar can be applied continuously for detecting the atmosphere with high accuracy. For laser applications in the atmosphere it is very important to provide the necessary atmospheric data. Recently the mobile lidar for detecting water vapour and aerosol simultaneously had been developed in China[1]. But the accuracy of the instrument should be further improved.

Generally, for lack of real time water vapour measurement the discussion limits to laser wavelengths without absorption of water vapour. In such case the AAEC inverted from single wavelength to multi wavelengths can be ensured for good accuracy. That is, in the near infrared spectrum the following strong absorption band 1.38 $\mu$ m, 1.87 $\mu$ m and 2.7 $\mu$ m and weak absorption band 0.94 $\mu$ m and 1.1 $\mu$ m of water vapour are not included in our discussions.

Laser radiation through the atmosphere will be absorbed and scattered by atmospheric components and aerosols. So that the attenuated laser beam also carries a variety of information of the atmosphere. How to extract atmospheric information itself correctly from the return laser beam is a key for whether the inversion method can be accepted or not. The proposed conjunction inversion method applies the laser return data measured at real time for extracting the atmospheric information at laser detecting time through atmospheric radiation transfer model. So that the AAEC at other wavelength can be inverted at the same atmospheric condition as that when lidar return is detected.

The properties of the atmospheric radiation transfer models which applied widely at present have been discussed in detail in article [2]. The atmospheric radiation transfer models which many scientists devoted to investigate and develop for several decades are as a base for real time inverse algorithm for multi wavelength's AAEC. Because these atmospheric models include in 6 kinds of typical model atmosphere in which there are different profiles of pressure, temperature, air density, density of water vapour and ozone. That is, those model atmosphere include in tropical atmosphere(15°N , mid-latitude summer 45°N July , mid-latitude winter(45°N January , sub-arctic summer 60°N July , sub-arctic winter 60°N January and American standard atmosphere. Besides those the model atmosphere also include in atmospheric aerosol models which fit different height region, i.e. boundary layer (0~2km), troposphere (2~10km), stratosphere (10~30km) and upper atmosphere (30~100km). In the boundary layer when meteorological visibility is in the region of 2~50km the aerosol models are distinguished into rural, urban, oceanic, tropospheric, navy oceanic and desert etc.. There are also other two foggy aerosol models, dense fog (visibility < 200m) and light fog (visibility = 200- 1000m), and rain and cloud models. Both aerosol spectrum distribution and refractive index variation with wavelength have been skilfully treated in these aerosol models. And, humidity correction of refractive index is also considered in right way. In consequence AAEC at other wavelengths can be inverted correctly from single wavelength lidar measurement by the atmospheric radiation transfer model. The inversion model which utilizing both real time detecting data and atmospheric radiation transfer model have both properties of the accurate atmospheric model and measurement in realtime. When the atmospheric radiation transfer model is applied atmospheric conditions should be considered and aerosol species should be selected. Obviously it is more reasonable and more accurate than other methods[4,5] which without any consideration of the atmosphere itself..

### 3 Comparison of results obtained by different inversion methods

AAEC value measured in real time and inversed by different methods are listed in Table 1 for wavelengths 0.532 $\mu$  and 1.064 $\mu$ . Among them the measured data is taken from [4] and inversed data include the following 2 parts:

(a) AAEC value obtained by use of the following relation [4,5] between visibility and AAEC:

$$V = (3.912 / \delta(\lambda)) (\lambda / 0.55)^{-q} \quad (1)$$

$q = 1.6$  when horizontal visibility is very fine  $q = 1.3$  when the horizontal visibility is middle

$q = 0.585V^{1/3}$  when the horizontal visibility is less than 6 km.

(b) AAEC value inversed by using atmospheric transfer model Fascode.

Table 1 Measured and inversed value of AAEC at wavelengths 0.532 $\mu$  and 1.064 $\mu$

Weather conditions		Vis. (km)	AAEC $\text{km}^{-1}$					
			0.532 $\mu$			1.064 $\mu$		
			Measured	Inverted from Vis.	inverted from Fascode	Measured	Inverted from Vis.	inverted from Fascode
Mist	-	1.9	1.1354	2.1092	2.1465	0.9717	1.2764	0.9551
		2.0	1.0917	2.0046	2.0394	0.9118	1.2027	0.8993
Haze	Rain	2.8	0.8634	1.4360	1.5286	0.5941	0.8109	0.7839
		4.0	0.5367	1.0087	1.0966	0.3730	0.5299	0.5732
Haze	Rain	5.9	0.3472	0.6868	0.7749	0.2210	0.3301	0.3660
		10.0	0.2479	0.4085	0.4624	0.1013	0.1659	0.2190
Fine	-	18.1	0.0701	0.2280	0.2289	0.0553	0.0752	0.0728
		20.0	0.0545	0.2063	0.2073	0.0507	0.0681	0.0656
Clear	-	23.0	0.0514	0.1794	0.1804	0.0437	0.0592	0.0566
		50.0	0.0223	0.0825	0.0834	0.0138	0.0272	0.0243

For the 0.532  $\mu$ , it can be seen clearly from the table, the AAEC values inverted from Fascode are nearly the same as that inverted from visibility. This means that aerosol species and atmospheric model are selected correctly when AAEC inverted by Fascode. As known, wavelength 0.532  $\mu$  is very near 0.55  $\mu$  for the wavelength defined visibility. Impact by molecule and aerosol scattering are nearly the same for both wavelengths. But for 1.064  $\mu$ , due to far from the wavelength defined visibility the inverted value by eq. (1) are effected by inaccuracy of the formula. It is clear that the two values inverted by different methods are not the completely same, but difference is still very small. In consequence, AAEC values for other wavelengths can be inverted by utilizing Fascode model and the selected aerosol species.

From the table it can be found that the detected AAEC provided by paper[4] are quite different from the value inverted by use of visibility formula (1), especially in weather conditions of haze and haze with rain. These defects are probably caused by the following problems: (a) variations in aerosol particles' refractive index with different wavelengths are not considered in a right way; (b) humidity correction of refractive index is left out of account. For example, real part and imaginary part of water refractive index are  $n_r = 1.335$  and  $n_i = 1.00 \times 10^{-9}$  respectively at wavelength 0.5 $\mu$ , but they are  $n_r = 1.327$ ,  $n_i = 2.89 \times 10^{-6}$  at wavelength 1.0 $\mu$  and  $n_r = 1.306$ ,  $n_i = 1.1 \times 10^{-3}$  at wavelength 2.0 $\mu$ . It is obviously that the difference of radiation attenuated by rain particles is very large for different wavelength. Moreover, very large difference between AAEC values inverted by visibility formula (1) and measured by [4] can also be found in the clear weather condition. Besides of above reasons atmospheric molecule scattering should be taken in inversion calculation in the region of shorter wavelength.

According to the above analysis and discussions the AAEC values for multi wavelengths can be inverted by utilizing meteorological visibility through atmospheric radiation transfer model Fascode when the correct data detected by lidar can not be obtained. The accuracy of the results inverted by this method depend upon the accuracy of visibility measurement but not upon the relationship between visibility and AAEC. It must note that the

wavelength region should be limited if the formula (1) is needed to invert AAEC. The relation (1) was proved by Curcio et al in 1961 for spectral region 0.40-2.27 $\mu$  under the following atmospheric condition : relative humidity 26-100%, meteorologic range 5.5-97 km. If the spectral region is expended to mid. infrared or far infrared the AAEC inverted by Eq. (1) appears to be wavy for haze atmosphere. The relationship between visibility and AAEC is lost on effects. In consequence, the results calculated by the formula (1) in the complete spectral region from 0.532  $\mu$  to 5  $\mu$  may be with large error or wrong.

#### 4 Real-time AAEC profile inverted by the proposed method for multi wavelengths

The widest and the most important application of laser in the atmosphere is from ground to space or vice versa. And it is very difficult to measure atmospheric visibility along slant or vertical path. So that how to invert AAEC profile from data detected by general single wavelength lidar to multi specific wavelengths is an important subject in practical laser application in the atmosphere. In order to prove the new inversion method the following discussion will concentrate on inversion of multi wavelengths' AAEC profile from data measured by 0.532 $\mu$  lidar. The real time data detected by 0.532  $\mu$  lidar are taken from [1]. A profile of the atmospheric aerosol at measuring time can be obtained from the measured data by fitting approach through the atmospheric radiation transfer model Fascode. Based on the profile of the atmospheric aerosol the AAEC for multi wavelengths can be obtained by utilizing Fascode in the same atmospheric conditions as that measured by 0.532  $\mu$  lidar. Fig. 1 shows the AAEC profile for multi wavelengths inverted from measured data by 0.532  $\mu$  lidar. It can be found from Fig. 1 that the AAEC profile for 0.532  $\mu$  wavelength is nearly the same as that for 0.55 $\mu$  wavelength. This is because not only these two wavelengths are very close but also there are no strong selective molecular absorption at these two wavelengths. However, at the other wavelengths, we can see that values of AAEC decrease with increasing wavelength but their tendencies of variation are nearly the same as that for 0.532 $\mu$  wavelength. Moreover, from Fig. 1 we can also find that the height region from 80 m to 10 km is utilized for the method test. This is because molecular scattering is over aerosol scattering at height 6–7 km. When scattering attenuation needs to be considered both molecular and aerosol scattering should be evaluated in the high level. If a variety of dust particles suspended in the atmosphere at high level, for example, a volcano bursting into eruption, it is convenient to apply the related data base in the atmospheric radiation transfer model Fascode for inverting AAEC.

Reference [1] noted that profile of AAEC and water vapour can be measured by lidar system simultaneously. Unfortunately, they did not give the simultaneous measurement data. In order to avoid effect of water vapour on AAEC inversion we specially select wavelengths without water vapour absorption. In practical, at wavelength 3.47 $\mu$  there are very weak absorption of water vapour. So that it could be with certain error for inversion of AAEC at this wavelength, but the calculation result shows that the error can be neglected.

However, the atmospheric molecular absorption should be taken into account at the wavelength when the atmospheric transmittance needs to be calculated. For example, both 0.532 $\mu$  and 0.55 $\mu$  appear very weak O<sub>3</sub> molecular absorption because they are within 0.44-0.74 $\mu$  O<sub>3</sub> absorption band (Chappuis absorption band its central wavelength is near 0.60 $\mu$ ). But at wavelength 1.57 $\mu$  it appears CO<sub>2</sub> absorption. The atmospheric radiation transfer model Fascode can be applied for calculating accurately the weak absorption. However, only the aerosol effect on laser transfer in the atmosphere is emphasized in the inversion calculation because the AAEC inversion method is discussed here. The molecular absorption of atmospheric compositions are not included.

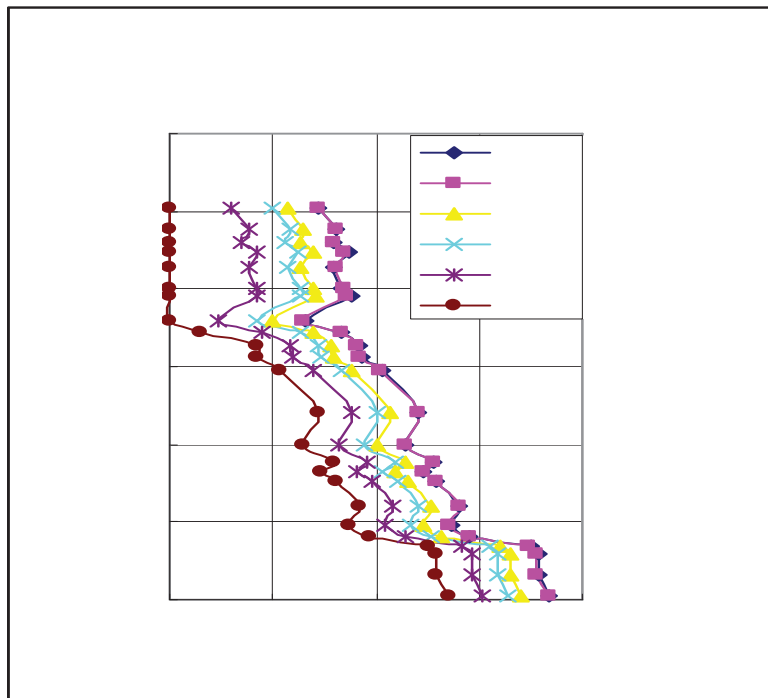


Figure 1

## 5 Conclusions

The information of atmospheric signatures carried in lidar return signal can be extracted by the atmospheric radiation transfer model. AAEC for multi wavelengths can be inverted at the same atmospheric condition as that measured by single wavelength lidar. In Consequence real time inversion can be realized. The validity and accuracy of this method has been proved by comparison with other inversion methods. The method is suitable for real time atmospheric correction of infrared target radiation transfer in the atmosphere. Especially, the real time AAEC inversion profiles for slant path from ground to space or vice versa for multi special wavelengths are valuable for many applications, e.g. for optical communication, satellite remote sensing, catching and attacking millitary target, and so on.

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